APPLICATION OF NANOFLIUDS IN SOLAR PV-T SYSTEMS

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Abstract: *the article describes a theoretical optimization process for designing nanofluid-based filters for hybrid solar photovoltaic/thermal (PV/T) applications. This particular application is suitable because nanofluids can be utilized as both volumetric solar absorbers and flowing heat transfer mediums based on five PV cells: InGaP, CdTe, InGaAs, Si, and Ge. This study demonstrates that nanofluids make efficient, compact and potentially low-cost, spectrally selective optical filters, which will provide with essential equipment energy corporations.*
Keywords: *hybrid; nanofluid; optical filter; photovoltaic; solar energy; solar thermal equipment.*

ПРИМЕНЕНИЕ НАНОФЛЮИДОВ В СОЛНЕЧНЫХ PV-T СИСТЕМАХ

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Аннотация: *в статье описывается теоретический процесс оптимизации проектирования фильтров на основе нанофлюидов для гибридных солнечных фотоэлектрических/тепловых (PV/T) приложений. Это конкретное применение является подходящим, поскольку наножидкости могут использоваться как объемные солнечные поглотители, так и как текущие среды теплопередачи на основе пяти фотоэлементов: InGaP, CdTe, InGaAs, Si и Ge. Это исследование демонстрирует, что наножидкости делают эффективные, компактные и потенциально недорогие, спектрально-селективные оптические фильтры, которые будут обеспечивать необходимым оборудованием энергетические корпорации.*
Ключевые слова: *гибрид; наножидкость; оптический фильтр; фотоэлектрические; солнечная энергия; солнечное тепловое оборудование.*

The aim of this study was to develop optimized nanofluid-based filters to match with several PV cell options: InGaP, CdTe, InGaAs, Si and Ge. These PV cells were chosen to demonstrate the versatility of nanofluid filters over the entire solar spectrum. The following sections describe the process used in this study to achieve optimized filters for these cells.

To obtain nanofluids with optical properties corresponding to the spectral response of these cells, the bulk materials were chosen carefully. As a starting point for modeling, this study reviewed optical property data for many materials from the handbook edited by Palik [1]. Most pure materials have either very broad absorption or absorption outside solar wavelengths. As such, the list of suitable materials is relatively short, including: doped semiconductors, metals and core/shell composite nanoparticles. Doped semiconductors present a feasible nanoparticle material choice because they absorb and transmit light in a similar range as PV cells.

Due to their strong plasmon resonance over a short spectral range, some metals are well suited to this application. Noble metals are a particularly attractive subset because they are resistant to oxidation and corrosion. Lastly, core/shell nanoparticles are attractive as well because the shell to core radius ratio can be controlled to tune optical absorption [2]. Likewise, they can have more pronounced absorption peaks than pure metals and use considerably less metal material, which represents a potential cost benefit over pure metal nanoparticles. Thus, core/shell nanoparticles with noble metal shells were chosen as a focus of this study.

To achieve volumetric absorption—where light is absorbed over a finite light path inside the fluid—the particle volume fraction was assumed to be in the range of 0% – 0.1% by volume. That is, for a relatively thick volumetric absorber (100 mm), only a low volume fraction of particles (i.e., less than 10^{-5}%) was needed to absorb the wavelengths of interest. For a thin filter (0.1 mm), volume fractions near 0.1% by volume were required for sufficient absorption.

Nanoparticle sizes in the range of 20 – 50 nm in diameter were used in this study. This size constraint assured that particles followed the flow, did not foul and/or abrade pumps and plumbing, and were available ‘off-the-shelf [3]. Table 1 summarizes the design parameters used in this study. It should also be noted that nanofluids should be stabilized for long-term operation in real-world applications, but this is outside the scope of this work.

Table 1. Estimated PV cell spectral response parameters

Cell type	**Short λ response edge (nm)**	**Long λ response edge (nm)**
InGaP	444	666
CdTe	500	750
InGaAs	589	884
Si	751	1126
Ge	1270	1906

Volume fraction optimization

The volume fraction, f_V, of the each type of nanoparticle was a key parameter for optimization in this study. This was determined by calculating the extinction coefficient from the following equation [4]:

$$\sigma_{\text{particle i}} = \frac{3}{2}\frac{f_V Q_{\text{ext i}}}{D}$$

where i represents the ith particle and Q_{ext} represents the extinction efficiency of the particle. It should be noted that this is only valid for small particle, low volume fraction nanofluids, i.e., the constraints of Table 1. Since the base fluid can contribute to the extinction of light through a nanofluid, this study assumes that the total nanofluid extinction coefficient is a simple addition of the base fluid extinction coefficient and that of the particles, defined as the following:

$$\sigma_{\text{total}} = \sigma_{\text{particles}} + \sigma_{\text{fluid}} \qquad (1)$$

Note: This approximation has been shown to be experimentally valid. By varying the thickness of the base fluids, the most suitable base fluid configuration for each type of PV cell was determined. Beer’s law provides a good first-order spectral approximation of the amount of light transmitted/absorbed by these fluid filters [4]:

$$T = 1 - \alpha\frac{I}{I_0} = e^{-L\sigma_{\text{total}}} \qquad (2)$$

where T is the transmittance, α is absorbance, I is the transmitted irradiation, I_0 is the incident irradiation and L is the length of the light path in the filter. This simple calculation does not separate the effect of scattering. For a nanofluid filter, scattering (i.e., lost solar energy) should be much less than 10% of total extinction (note: small particles scatter much less than large particles). In this study, low scattering was assured by putting a constraint of 0.1 for the ratio of scattering efficiency to extinction efficiency.

To determine the efficiency of a nanofluid as a band-pass filter, this study used the following partitioned integral:

$$\eta = \frac{\int_{short\lambda}^{long\lambda} E_\lambda T_\lambda d\lambda}{\int_{short\lambda}^{long\lambda} E_\lambda d\lambda} - \frac{\int_0^{short\lambda} E_\lambda T_\lambda d\lambda}{\int_0^{short\lambda} E_\lambda d\lambda} - \frac{\int_{long\lambda}^{4\mu m} E_\lambda T_\lambda d\lambda}{\int_{long\lambda}^{4\mu m} E_\lambda d\lambda} \qquad (3)$$

where E_λ is the amount of solar irradiance per unit wavelength—data for E_λ can be obtained from Gueymard [5]. A perfectly transparent (T=1) filter between the short and long edges shown in Table 2 which is also perfectly absorbing (T=0) outside of that range, will achieve an efficiency of 1. Thus, Equation (8) is the objective function for filter optimization. This study uses a simple Monte Carlo approach to randomly generate volume fraction combinations which can be sorted by η to find the optimum filter.

The goal of this study was to demonstrate the versatility of novel nanofluid collectors and several potential avenues were identified for future work. The effect of stabilization agents (surface chemistry modification) and linker agents (such as silanes) which are necessary in the fabrication process is unknown. The addition of many more particles to achieve more complex filtration could help to achieve a better filter. Experimental studies are needed to measure filter performance. Lastly, for real applications, an economic optimization based on the price of fabrication and the relative value of electricity vs. heat (based on location) is needed.

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